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CENTRAL INTELLIGENCE AGENCY
INFORMATION FROM
FOREIGN DOCUMENTS OR RADIO BROADCASTS

REPORT
CD NO.

50X1-HUM

[redacted]

COUNTRY	USSR	DATE OF INFORMATION	1948
SUBJECT	Scientific - Machine-building theory		
HOW PUBLISHED	Monthly periodical	DATE DIST.	14 Apr 1950
WHERE PUBLISHED	Moscow	NO. OF PAGES	5
DATE PUBLISHED	Feb 1948		
LANGUAGE	Russian	SUPPLEMENT TO REPORT NO.	

THIS IS UNEVALUATED INFORMATION

SOURCE Vestnik mashinostroyeniye, No 2, 1948

50X1-HUM

PROBLEMS OF STABILITY IN SOVIET MACHINE CONSTRUCTION

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Developments in present-day machine building require close cooperation between the various research institutes of the industry. For example, the advances in the field of gas turbines have been made possible by successes in the field of better heat-resistant alloys and improved means of joining vanes to disks, while in the field of railroading, better rolling stock is the result of research with thin sheeting, new steels and lighter alloys. At the same time new technological processes in the field of chemistry require the development of new containers which can be used under high pressures and temperatures.

Rapid advances in the technology of machine building have outmoded many methods of calculating the rigidity of machines. New designs, materials and technology require great expansion in the field of experimental methods of studying rigidity and fatigue-resistance of parts.

Today the rigidity of machine parts and the design of machines are determined by actual operation of the equipment, as well as by design and technological factors. An analysis of the evolution in design in such fields as Diesel, locomotive, engine, turbine, and electrical-machine building shows the value of working factors in determining the rigidity and wearing quality of various parts. Most important among these factors are the dynamics of loading and fatigue of the materials. In the majority of machine units, such factors as acting forces and strains appear only during operation of the machine. For example, in Diesel engines there are stresses which act on the connecting rod at every revolution, due to gas pressure and the inertia of the moving masses. In internal-combustion engines there are various stresses arising out of fluctuating loads. In pneumatic hammers, stresses and strains affect the apparatus every time that the hammer strikes the base plate. In all of the above cases it is usually the secondary strains and tensions which lead to breakdowns.

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Now, due to use of high-speed equipment, it is necessary to develop new means of calculating strains and stresses with a high degree of accuracy. However, there are still many fields where it is possible to make only approximations (as in the case of turbines with small vanes). It is also necessary to improve methods for determining the causes of vibration in machines. Present methods of measuring small deformations and converting them into statistical and dynamic expressions permit wider experimental determination of frequency of vibrations. Truth of this statement is borne out by the fact that the actual bending resistance of a tractor crankshaft has been shown to be twice the theoretical resistance. The significance of resonance vibration, which occurs in machines in a wide range of frequencies, should also be remembered. Research on this subject has permitted technicians to obtain new results in the field of compressor vibration.

Complex designs, electric, mechanical and hydraulic blocking in individual units, increased dimensions, and in some cases lower rigidity of weight-bearing structures in machines have increased the need for solving problems of compound oscillation in mechanical, electric and hydraulic systems.

Due to the saturated spectrum of periodic excitation forces, which can be observed in turbines high speed reciprocating engines and metal-working machine tools, it is necessary to determine tensions in terms of resonant and single-force oscillations. Deformation and tensions, which appear as resonance factors, are determinable primarily in torsion oscillations. In this respect it was possible to use the expression which shows the balance between the excitation force and the action of damping. Solving problems dealing with bending oscillations is somewhat more difficult due to the backlash and lubricating film on bearings and other contacts.

Continuous theoretical and experimental research is being conducted to solve problems dealing with those factors related not only to the damping properties of metal but also to the design of machines and their parts. For the purpose of determining tensions which appear during resonance, it is necessary to know not only oscillation-resistant but also the excitation forces. While at present such forces are calculated on the basis of dynamic data in crankshaft and connecting-rod mechanisms, it should be remembered that some factor which upset the constant of cylinder combustion will affect in varying amplitudes the harmonically tuned gas forces. Consequently the excitation is not strictly periodic and must also be classified as static.

Calculation of excitation forces is much more complex in machines which are equipped with vanes (turbines, compressors, etc.). These forces are gas-dynamic, and their harmonic nature and intensity must be determined by placing measuring equipment across the gas or steam jet as it passes through the nozzle. The character of the flow against the vanes of the turbine has also to be studied.

In machine tools, the vibrations which arise during operation have an auto-oscillatory character. They are closely rated to the dynamics of the cutting process and dynamic properties of the machine tool. Research in these fields is still new and much progress is forseen for the near future.

Complex calculations are necessary for determining the oscillation strains in elastic systems which have much free play when subjected to complex excitation forces. After obtaining theoretical data, models are made up and tested by electro-mechanical means. At present, this electric method of testing models and mockups is being used to solve oscillation problems.

Due to the complex structure of oscillatory systems and the excitation characteristics in present-day machinery, there is need for wide use of specially designed shock-absorbing units. Both inert and absorptive shock absorbing is being utilized in reciprocating engines. In the case of the vanes in turbines it would be most advantageous to increase the shock-absorbing properties of the metal itself and its various connections. It is interesting to note that greater use is being made of elastic and absorbtive-type bonding (rubber buffer type) in various types of machine bases.

A few words must be said of impulse forces and fatigue resistance. Shock loads are experienced by many types of machinery. The theoretical determination of these forces is complicated and difficult. However, current use of such apparatus as the electric-resistance tensometer, high-speed photography, the piezoeffect, and many other methods make it possible to study the mechanisms of both elastic shock, and shock in the presence of plastic deformation and viscous resistance. Solution of problems in this field will permit better calculations of stability, will clarify problems connected with shock deformation and will lead to theoretical solution of the above problems.

Before discussing stresses on parts in relation to their shape, we must go briefly into some static factors of machine building. Many calculations are made on the basis of simple force diagrams which do not show the actual nature of the deformation forces. For example, calculations on bolted joints are usually made without regard to the rigidity of the parts which are being joined. Many supporting beams are treated as though they were section beams.

Further solution of static factors in elastic systems of machine parts and units must be based on results of theoretical calculations and experimental data. Thus it will be possible to check the reliability of present-day computation methods, as well as to make better evaluations of the significance of rigidity in load capacity and design stability.

It must be kept in mind that excessive deformation leads to overloading and subsequent damage to operating parts of machines.

The use of thin sheet is becoming more and more popular in construction of railroad cars, cranes, and other heavy units. With modern methods of calculation, it is possible to determine deformation in thin-sided section beams. But making primary calculations for force diagrams prior to design and production of a given unit requires new methods of computation. Further research is necessary in the field of local stability outside the elastic limits to determine the actual load-bearing capacity of thin structures.

The complexity of geometric calculations for parts design, the necessity of using all types of cutting tools, stamped parts, and welded as well as cemented joints, result in irregular dispersion of stresses, as well as improper utilization of material for parts.

Load dynamics, i.e., the alternating nature of strains and their unequal distribution throughout the machine parts are the primary causes of fatigue in machinery. Fatigue is the result of the accumulation of slight deformations in individual crystals of the machine part.

Consequently, if the relationship between acting forces and mechanical stability of the material is known, fatigue flaws will appear in the machine parts after a predictable period of operation. Such flaws can develop into serious breakdowns. These flaws, which start as local damage, eventually affect the operation of all the small parts in a machine. Therefore, the geometric calculation of parts design, the determination of concentration of strains acting on the parts, and the finish of the parts' surfaces are the determining factors in the fatigue resistance and stability of a machine part.

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Generally, there is considerable difference between the theoretical fatigue resistance of parts, as determined on the basis of laboratory experiments, and the actual stability of the metal. For example, it has been determined in the laboratory that the permissible load on an alloyed steel crankshaft of a high-speed internal combustion engine is around 30 kilograms per square millimeter. Actually, however, the permissible load on such a crankshaft is only 10 kilograms per square millimeter, or one third of the theoretical load limit. Another case: axles made of very tough steel have a theoretical fatigue resistance of 35 kilograms per square millimeter. In practice, however, the fatigue limit of a 200-millimeter-diameter axle is about 7 kilograms per square millimeter.

Such errors occur from failure to take into account such forces as load dynamics, unequal distribution of load and the fatigue-resistant properties of the materials involved.

Design improvements as well as improved distribution of loads has greatly raised the fatigue resistance limit of such products as beams, axles, various types of joints, etc. Experimental testing methods have also played an important role in increasing this fatigue-resistant limit.

By means it is possible to decrease strain concentrations by some 10 percent and to distribute the strains more evenly over the area of the machine part. The use of resistance tensometers and lacquer films have made it possible to observe the effects of static and dynamic loads on the surface of metal parts. Optical methods of measurement help to establish the volumetric strain on a part, while use of the creep properties of optically active plastics facilitates study of stresses incentrifugal fields and beyond elastic limits.

Utilization of methods based on the theory of elasticity and plasticity for studies on parts subjected to stress will lead to a deeper understanding of the distribution of strains and elastic displacement of various machine parts. At present, scientists have already solved many problems in the field of plastic deformation (under conditions of creep and shock loading) where the speed of deformation has a significant effect on the distribution of strain. Improvement of approximate and computed solutions of problems, and coordination of experimental and theoretical data will widen the scope within which such data can be used in the designing of new machine parts.

Improvement of techniques for finishing surfaces and increasing the fatigue resistance of annealed steels will result in greater productivity of various operations. Present day methods of hardening metal surfaces by nitriding, surface annealing, etc., will lessen the d ,endance of the stability of metal parts on the quality of the finishing process. This will result in simplification of the finishing processes and permit the use of higher stability steels in machine building. It will also result in the adoption of new methods of hardening surfaces such as chemico-thermal processing and surface cold-hardening.

The following examples will illustrate the achievements already made in this respect. Practical tests for fatigue resistance on nitrided crankshafts showed that the resistance increased 1.5 times as a result of the nitriding. Spraying very hard steel with pellets increased the fatigue tolerance from 60 kilograms per square millimeter to 100 kilograms per square millimeter.

In spite of the remarkable practical achievements in the study of fatigue resistance, some solutions are purely hypothetical and in other cases contrary to accepted practice. Plastic deformation, polycrystals, physical and chemical processes and their associated cyclic deformations, the phenomenon of frangibility and changes in residual strains need further study. Particular efforts must be made to further the study of temperature and gas-corrosion effects on fatigue resistance in heat-resistant alloys, these having direct bearing on developments in vane-equipped machines such as turbines, generators etc.

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Irregular performance due to alternating strains demands a systematic study of the phenomenon of succession of cyclic deformations, so as to obtain greater accuracy in determining wearing quality of parts. This is particularly necessary in cases of contact tensions and high temperatures when there is no determined fatigue limit but when the wearability of the part has a determined value. Engineers and physicists still have much research to do in the field of cyclic processes in connection with asymmetry, phase and frequency. Further study of the physical and chemical factors affecting fatigue should be carried out simultaneously with studies in the durability of machine parts.

In present-day technology, such factors as continued stability and creep at high temperatures are just as important as variable loading. Many hours of research have already established a relationship between creep speed, stresses and temperature. This relationship has been put to practical use in solving problems of stress distribution in plastic materials where creep is present. However problems dealing with contact strains and concentrations of load still have to be solved. Very little is known about relaxation, and the problems dealing with strains occurring during relaxation are still clouded in ignorance. The whole process of stress changes, from the rigid state to the state where creep first becomes noticeable, can only be understood through the relaxation problem. Such solutions are particularly important in cases where machines have to work for short periods at very high temperatures. The science of computing thermal stress in machine parts will obtain added impetous from the study of the relationship of creep and relaxation, the criterion of plasticity at high temperatures, and the effects of repeated heatings.

Little is known of plastic deformation and fracturing under high temperatures. This makes it difficult to confirm much experimental data and many laws of machine performance. Research on the kinetics of structural changes and resistance to plastic deformations at high temperatures must be carried out.

Experimental data obtained in the laboratory still does not solve many of the problems connected with stability and endurance at high temperatures and under conditions of concentrated stresses and revolution. Today, industrial engineers can avail themselves of graphs and data which show permissible stresses which take into account such factors as creep, stability, and endurance under simple and homogeneous stresses. However, methods of computing the stability of machine parts operating under high temperatures and complex stress distributions must still be worked out.

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